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Published in:
Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'02) Lisbon, September 2002

DOI (link to publication from Publisher):
10.1109/VETECF.2002.1040664

Publication date:
2002

Document Version
Publisher's PDF, also known as Version of record

Link to publication from Aalborg University

Citation for published version (APA):
Pedersen, G. F., & Nielsen, J. Ø. (2002). Radiation Pattern Measurements of Mobile Phones Next to Different Head Phantoms. In *Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC'02) Lisbon, September 2002* https://doi.org/10.1109/VETECF.2002.1040664

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Radiation Pattern measurements of Mobile Phones next to different Head phantoms

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Abstract—**An investigation of the radiation from 5 different phones next to two head phantoms proposed for radiation measurements has been carried out and the radiation has been evaluated thru the Total Radiated Power, the Total Receiver Sensitivity and the Mean Effective Gain. The investigation is based on measurements of the farfield patterns measured in an anechoic room using a system tester to avoid any disturbance of the radiation patterns.**

The results shows that the losses due to the phantom heads are twice as high in dB values, at 900 MHz compared to 1800 MHz. Even though the two head phantoms are rather different in shape it is concluded that the influence by the phantom on the radiation is the essentially same

Keywords—Total Transmitted Power, Total Receiver Sensitivity, Mean Effective Gain, Phantom, Measurements.

I. INTRODUCTION

For all modern systems for mobile communication where many vendors of both the infrastructure and the mobile phones deliver equipment, common interfaces are needed. One of the perhaps best-specified interfaces is the radio interface where both the mobile phones as well as the base stations from different vendors need to communicate. This is ensured by a detailed description of its operation as well as a specification on how to test that the equipment fulfils the requirements. This is also the case for the mobile phones today but nearly all tests on the phones are done at the RF-terminal. The reason for using the RF connector and not the antenna output is purely practical. But as the phones have developed over time very different designs of antennas, transceivers and the phone cases have been made and the communication performance has varied significantly among the phones [1]. Especially the network operators that receive complaints from the mobile users and need to use more network resources to keep an acceptable link quality for the poor designs have been concerned [2]. For the second Generation systems (2G) this has lead to several self-made test procedures, which are very different from operator to operator and region to region, and some of the tests even contradict each other. It is not easy to make a test that reflects the real situation due to lack of solid technical knowledge in the area of communication performance of mobile equipment. The communication performance of mobile equipment including the antenna is very different to traditional fixed high gain antennas in the sense that no traditional antenna parameters are obvious. Typical parameters such as peak gain and co-polarisation cannot be used as the mobile end can literally take any position relative to the other end. Further, the mobile equipment is influenced by nearby objects, which often is the user [3,4]. Based on several studies of the communication performance of mobile phones in the real situation, i.e., typical mobile environments including a large number of persons, phones, positions etc. [2] it is clear that the test needs to include the typical user position which is very different for different types of User Equipment (UE), e.g. phones, data terminals, video phones, arm wrist devises, pagers and other types of UE which can be expected to come in the future. The most common UE type today is the phone and the typical use is next to the human head.

This work investigates two different head phantoms proposed for radiation measurements and compare both the total transmitted and received powers as well as the Mean Effective Gain (MEG). MEG is the power received by the UE in a typical environment relative to a reference. The environment investigated in this paper is the outdoor to indoor scenario in urban environments. The comparisons are based on absolute radiated and received powers measured as absolute values (in dBm) in each direction and polarisation on a sphere surrounding the UE. This is the approach first suggested by [4,5] and later adopted by e.g. CTIA [6]. The two head phantoms are the one used for SAR measurements from S&P [7] and the SAM head proposed by CTIA [6].

II. MEASUREMENTS

For the investigation 5 commercially available dual-band GSM900 and GSM1800 phones has been used. One large and one small phone with internal antenna, marked B and C, and one large and one small phone with helical antenna, marked A and F, were selected, as well as a small phone with an extractable half-wave dipole antenna marked E. These are the typical phones seen on the market.

The purpose of the measurements is to find the radiated and received power in all directions for both polarisations in the farfield. From the dual polarised spherical radiation patterns the Total Radiated Power (TRP) and the Total

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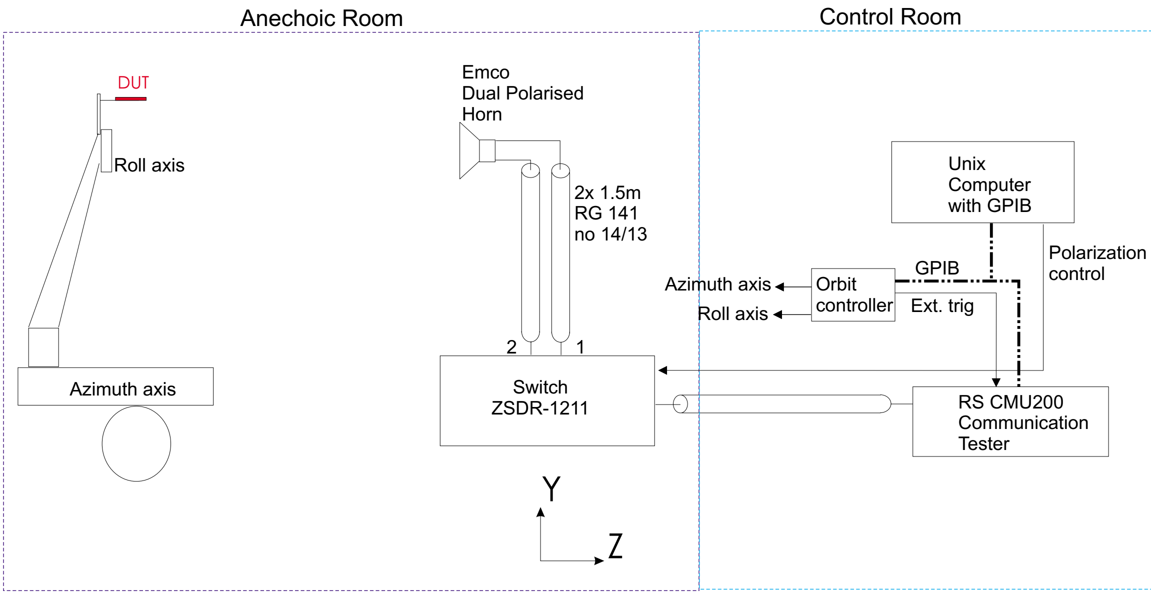

Figure 1 Blockdiagram showing the major components of the measurement system for measuring radiated and received power for a GSM phone. The setup is based on a system tester whereby measurements can be preformed without modifying the phones

Receiver Sensitivity (TRS) can be obtained by integrating the radiated or received power over the sphere. The radiated and received power is measured for all 5 phones both in free space as well as next to each of the two head phantoms at the centre channel of both the GSM900 and GSM1800 bands.
The advantage of measuring the spherical radiation patterns and not only e.g. TRP, is that the influence of the mobile environment can be included by post processing of the radiation pattern and a model of the incoming power in the mobile environment. The performance of the phone in the mobile environment is the so-called Mean Effective Gain (MEG) as detailed in [8,9], and described below.

The measurements are conducted in the anechoic room at Aalborg University in an automated setup capable of measuring both polarizations in any grid on a sphere, see figure 1. The anechoic room is a large room, 7 by 7 by 10 meters, and the distance between the rotating phone and the probe antenna is some 5.5 meters. The measurements are based on a system tester, here a CMU200 that acts as the basestation, which controls the phone. In this manner no modifications are made to the phone that could disturb the radiation. A measurement starts by the system tester initiating a call to the phone, which is answered on the phone by an operator, then the phone is fixed in the position for measurement and the program starts to measure the up- and downlink in each polarisation and then the pedestal moves to the next position. After all positions are measured the program moves to the position and polarisation of maximum received power and starts reducing the power transmitted by the system tester in steps of 0.25dB while the phone is reporting the received power. In this way the linarisation of the power measurements in the phone is obtained. By measuring a full sphere and both polarizations it is possible to calculate the TRP, TRS and MEG.

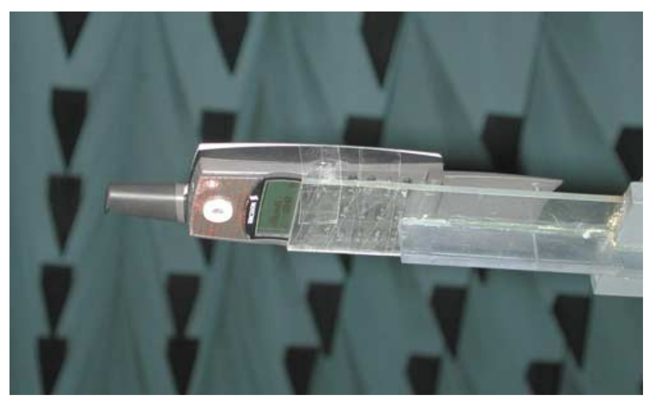

Figure 2. Jig for the measurements in free space, the phone is fixed by tape to the low loss low dielectric jig

In the present measurements the most important results are the total radiated or received power in each direction and polarisation and therefore no direct measurements of the antenna by it self were carried out. It should be noted that the antenna efficiency easily can be extracted from the measurements of radiated power if the assumption that the power delivered to the antenna from the power amplifier does not change due to different loading (load-pull of the power amplifier) are correct. Each spherical radiation measurement consists of 10 by 10 degree samples on a sphere, altogether 648 measured points dual-polarised. The sampling step is based on the electric size of the phone.

For the measurements in free space the phone is fixed by tape to a low loss low dielectric jig, see figure 2. For the measurements next to the head phantoms the phone is fixed by tape. The centre of the ear on the phantoms has a small plastic ring with fit exactly with the plastic ring mounted on the phone, see figure 2. The phones are aligned with the line from the ear to the mouth, see figure 3 and 4.

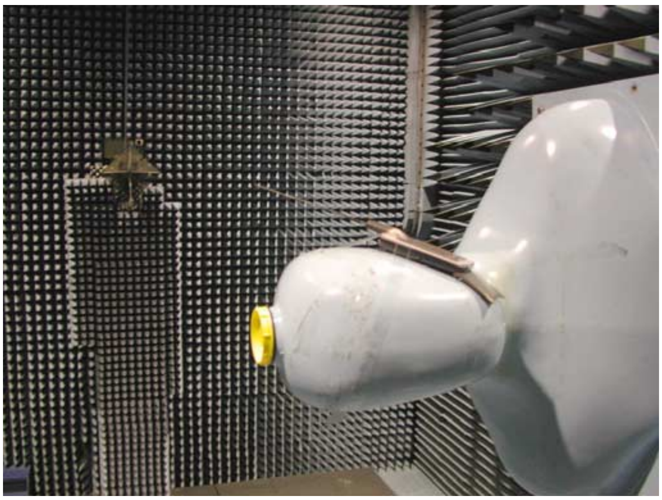

Figure 3 showing one phone during measurement on the Torso Phantom in the anechoic room.

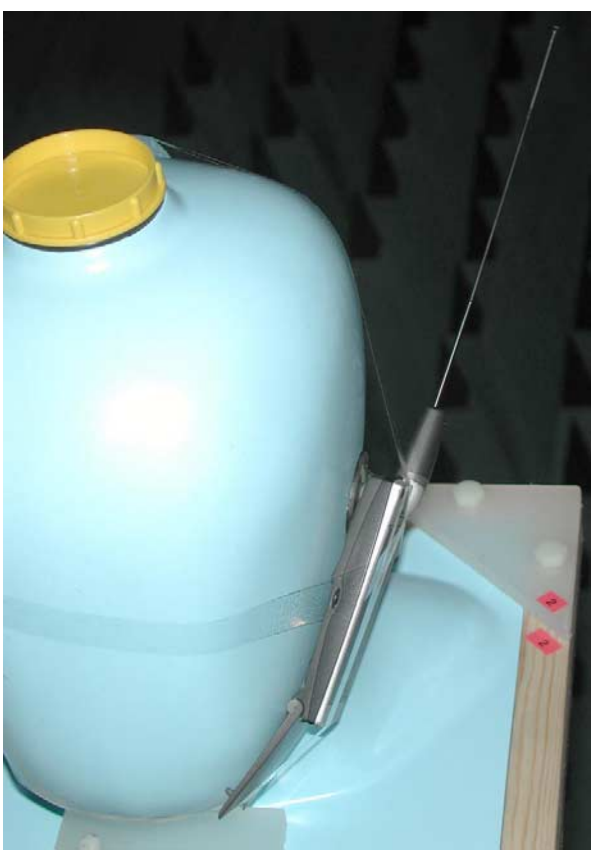

Figure 4 showing the phone during measurement on the SAM phantom.

A. Absolute Radiated Power Measurements

The absolute radiated power is a measure of the radiation pattern including the matching losses and the output power of the power amplifier in the phone. The measurements are based on the peak burst power including various system aspects, as the phone is an off-the-shelf product. The matching losses is not only the loss due to Standing Wave Ratio (SWR) stemming from different impedance matching but also the loss due to change in the power delivered by the amplifier due to a loading different from nominal – e.g. 50 Ohm (load-pull). As no modifications are made to the phones the measured radiated power is really the power available for communication and the radiation pattern it self is not altered due to external cables. Further, if limits are put on e.g. the minimum amount of radiated power this measure will include all parameters influencing the transmitted power. The absolute radiated power is measured at the centre of each GSM bands in the up-link i.e. 902 MHz (GSM900 Channel 62) and 1747 MHz (GSM1800 Channel 698).

B. Absolute Received Power Measurements

The absolute receiver sensitivity is a similar measure to the absolute radiated power just in the other direction i.e. from the basestation to the mobile phone. The most accurate way to measure, as specified in the GSM specifications, is to measure the Bit Error Rate (BER) and not the received power. As the measurements of BER is very time consuming and as there is a direct relation between BER and received power (RxLev in GSM) for each individual phone the RxLev is measured [10]. If the phone is measuring the received power well, no compensation for non-linear behaviour is needed. Although power sweeps have been measured for the phones in the anechoic room no compensation has been made, as a nice linear relation between the received power and the RxLev was found for the phones in this investigation and therefore, the down-link results are based on the reporting of received power from the phones. The absolute received power is also measured at the centre of each GSM bands in the down link i.e. 947 MHz (GSM900 Channel 62) and 1842 MHz (GSM1800 Channel 698).

C. Calibration and measurement uncertainty

The absolute power levels in both up- and down-link is obtained by a back-to-back calibration of all cables, switches, splitters, amplifiers and attenuators using a network analyser and calibration of the CMU by comparing to a peak power meter. The probe antenna is measured in a 3-antenna measurement setup to obtain the absolute gain, and the distance between the phone centre (which is centre of rotation) and the probe antenna is used to calculate the losses by Friis transmission law. To check the calibration a mobile phone was connected directly to a reference monopole antenna (one monopole antenna for 900 MHz and one for 1800 MHz) and measured similar to the phones in free space for each channel in both up- and down-link. The power transmitted by the phone was measured and compared to the power obtained by integrating the transmitted and received power over the sphere. The loss in the reference monopole was some 0.5 dB for all frequencies used.

To establish some confidence in the measurements and to find the level of repeatability two of the phones were measured 10 times in free space. Between measurements various changes were made such as measurements on fully charged battery compared to half charged battery and cold phone compared to phone which has transmitted on maximum power for two hours as well as disassembling the setup etc. The repeated measurements were interleaved with the other measurements throughout the time of all measurements for this investigation. The repeated measurements shoved a variation in both up- and down-link in TRP and TRS of only ±0.13 dB. The radiation pattern was investigated thru the MEG and an additional variation of less than ±0.16 dB was found for both up- and down-link. For the measurements including the phantom 3 repeated measurements of two of the phones were made to see if the positioning etc. results in a larger uncertainty. The variation in the TRP and TRS were less than ±0.05 dB and for the MEG it was less than ±0.14 dB when the phantom was included.

III. DATA PROCESSING

A. TRP and TRS

After the measured data is compensated as described above under calibration the TRP and TRS is calculated simply by integrating the power in both polarisations on the surface of the sphere:

$$P_{rec} = \frac{1}{4\pi}\oint\left\{ P_\theta(\Omega) + P_\varphi(\Omega) \right\}d\Omega$$

Where $P_\theta(\Omega)$ and $P_\varphi(\Omega)$ is the power received in each polarisation and Ω is solid angle.

B. Mean Effective Gain

The MEG is the ratio of the actually received mean power by the antenna (phone) under test to the mean power received by a reference antenna. The MEG can be obtained using a surface integration over the sum of the two polarization components of the radiation pattern, each weighted by a function. The two weighting functions model the mobile environment by the distribution of (incoming) power versus direction, as well as the cross Polar Ratio (XPR). More details can be found in [11].

In this work two models of the power distribution in the environment have been used. Both the HUT model [12] and the AAU model [10] are based on large collections of measurements where the transmitter is located in an urban environment and the receiving equipment is inside a building. The receiver can measure the incoming power for each direction and polarisation based on one or more directive antennas that can rotate or be steered in azimuth and elevation. The HUT model is based on an average over azimuth angle (uniform in azimuth), but non-uniform versus the elevation angle. The XPR is 10.7dB. The AAU model is non-uniform in both azimuth and elevation angle, and the XPR is 5.5 dB.

As both the radiation pattern of the phone and the power distribution model are non-isotropic, the MEG will depend on the orientation of the mobile with respect to the environment. Given that this is the situation in most cases when the phones are used in the network, it is important to investigate the resultant variation in the MEG. It is desirable to have as small as possible a variation in MEG due to the user orientation – this can only be investigated with a model also reflecting the variation in azimuth.

In this work the measured radiation patterns have been rotated in a post-processing step, so that the MEG is computed for all possible rotations in azimuth, in steps of 15 degrees and both typical and peak values are reported.

IV. RESULTS

The measured TRP and TRS values for both phantoms and the free space are listed in Table 1 and 2 for the 900 MHz and 1800 MHz, respectively. The influence of the phantom is largest at the low frequency band, i.e. the 900 band where the loss caused by the phantom is some 5 - 6 dB. At the high band the loss is only some 2.5 - 3 dB. An exception to the figures mentioned is the half wave extractable dipole antenna with a loss of some 1.5 dB for the downlink at both frequencies. The difference between the uplink and downlink is significant for some phones and may be caused by the change of output power due to the change of antenna matching caused by the head phantom (load-pull of power amplifier). Similar losses does not occur in the receiver and as no other explanation can justify the difference for the relative small frequency separation most trust is put on the TRS values when concluding on the losses in the phantom. The difference in MEG values, (MEG for free space and next to the SAM phantom) for all azimuth directions and all phones are between 3.9 dB – 5.7 dB for the AAU model at 900 MHz and 4.2 – 8.8 dB for the HUT model at 900 MHz. The lowest value is for the extracted antenna. The values at 1800 are slightly lower 1.8 – 4.5 dB for the AAU model and 1 – 6 dB for the HUT (for the HUT the lowest values are for phone B and F and the largest for the extractable).

PHONE	FREE SPACE TRP / TRS	SAM TRP / TRS	TORSO TRP / TRS
A	30.1 / +0.1	25.7 / -6.1	25.3 / -6.6
B	31.2 / -0.6	26.2 / -6.5	26.0 / -7.0
C	30.7 / -1.5	25.6 / -7.2	25.2 / -7.8
E	27.5 / -2.8	26.4 / -4.5	26.4 / -4.6
F	30.2 / -3.0	26.2 / -8.4	26.1 / -8.9

Table 1 TRP and TRS values for free space, the SAM phantom and the Torso at 900 MHz

Comparing the two phantoms the difference in TRP and TRS is less than 0.6 dB for 900 MHz and less than 0.3 dB for 1800 MHz. The difference in MEG using the AAU model for the two phantoms is typically 0.6 dB and maximum 0.9 dB for 900 MHz and typical 0.25 dB and maximum 0.7 dB for 1800 MHz.

PHONE	FREE SPACE TRP / TRS	SAM TRP / TRS	TORSO TRP / TRS
A	26.4 / -2.5	23.6 / -5.5	23.2 / -5.7
B	27.7 / -3.8	24.4 / -6.9	24.2 / -7.2
C	28.0 / -1.5	26.1 / -4.8	26.2 / -3.2
E	26.8 / -3.1	23.9 / -4.7	24.2 / -4.8
F	26.3 / -2.0	24.4 / -4.8	24.4 / -4.9

Table 2 TRP and TRS values for free space, the SAM phantom and the Torso at 1800 MHz

As the two phantom heads seem to have the same effect on the radiation 4 measurements were made at 1800 MHz with the Torso phantom including a phantom hand made of a rubber glove filled with the same liquid and positioned some 5 cm from the top of the phone. The TRP values showed an extra loss of some 2 dB for the small phones and some 4 dB for the large phones. For the TRS an additional loss of some 2 dB was found for all phones, which is in agreement with [4] for a low hand position, again indicating that the power amplifier significantly can change the performance when loaded with impedance different from nominal. The small phones are newer phones and may be more robust against load-pull effects. The difference in MEG comparing with and without the hand is typically only 1 dB but more than 3 dB for handset B.

V. Conclusion

Comparing the radiated and received power of the 5 different phones next to two phantom heads filled with the same liquid showed a small difference between the two phantoms in TRP and TRS of less than 0.6 dB and 0.3 dB for the 900MHz and 1800 MHz. The additional losses due to the phantom heads are some 6 dB for 900 MHz and 3 dB for the 1800 band.
Comparing the radiation patterns thru MEG the additional difference between the two phantom heads is typically 0.6 dB for the 900 MHz and again some half of the value in dB at 1800.

The difference in MEG between the free space and next to the phantom head is typically some 5 dB at 900 MHz and 3.5 dB at the 1800 band. This clearly demonstrates that the difference between the two head models is very small and very different from the free space case. But if any of the head models are correct models of the human head has not been proven yet.

VI. Referances

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